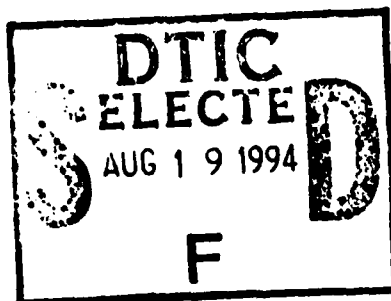


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THE FUTURE OF ASTRONOMY IN AVIATION

- USSR -

by N. A. Kondrat'yev

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THE FUTURE OF ASTRONOMY IN AVIATION

[This is a translation of Chapter Six, pp. 180-213, of *Astronomiya v aviatsii* (Astronomy in Aviation), 1959, 2nd edition, Moscow, 1959, by N. A. Kondrat'yev]

With each passing year, aeronautical astronomy acquires increasingly greater significance for the guidance of aircraft. This is accounted for by the fact that astronomical methods possess a number of advantages over other methods of guiding aircraft. Chief among these are the following:

1. The fact that the astronomical methods do not depend on ground installations, due to which an enemy cannot disturb their operation artificially. In this respect the astronomical techniques are favorably distinguished from radio methods of aircraft guidance.

2. Constant precision in the determination of the navigation elements over the entire extent of the flight, no matter how great the distance. This advantage comes to the fore particular-

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ly in long-distance and ultra-long-distance flights carried out beyond the effective ranges of radio-based systems. Under these conditions, neither radio methods nor automatic course reckoning (to say nothing of dead reckoning) can assure the necessary precision of guidance of the aircraft.

3. Their applicability anywhere on the Earth's surface. We know that guidance systems with magnetic sensors operate unreliably in the polar regions, while radio methods frequently fail due to natural disturbances in the propagation of radio waves. In the Arctic and Antarctic, therefore, astronomical techniques are ^{sometimes} the only ones that guarantee the feasibility and safety of flight.

These positive features of the astronomical methods form the basis for the further development of astronomy in aviation. Automation--the direction in which all engineering methods of aircraft guidance are being evolved--is also encompassing the astronomical methods to an increasing degree. Still more promising possibilities for their use are appearing with the development of a new branch of science and technology: radio astronomy. Even now, when flights are carried out to greater advantage at high altitudes, continuous cloud cover presents virtually no obstacle to the use of astronomical methods, since it rarely occurs above 6000 to 8000 m. The methods of radio astronomy make it possible to carry out astronomical determinations under all meteorological conditions and at any time of day. The conquest of cosmic space, which was begun with the launching of the first artificial earth satellite on 4 October 1957, has opened new prospects for aeronautical astronomy. Making use only of the Doppler effect, the crews of airplanes and the flying craft of the future will be able to determine certain elements of their flight courses from artificial satellites, in the same way as from the celestial luminaries.

Thus there is every reason to assume that astronomical methods will acquire ever-increasing "specific weight" among the methods of

aircraft and rocket guidance.

1. Automation of Astronomical Methods.

Automation has come into wide use in modern technology. Many industrial processes are carried out without the direct participation of man. He retains the functions of setting up the initial data, controlling the various aggregates, and monitoring their operation.

Automatic production lines and entire automated factories have come into being to replace the simplest automatic machines and devices. The development of contemporary technology without automation would be unthinkable.

The use of automation has not been restricted to industrial production. It has been introduced on a wide scale into all branches of the economy and even into the household.

The modern aircraft is equipped with complex instruments and systems which it would be practically impossible to control without the use of automation. It is even difficult to achieve guidance of an aircraft without recourse to automatic navigation devices. Therefore navigation instruments which automatically determine the coordinates of the aircraft's position, radiocompasses that automatically indicate the bearing of a radio station, astrocompasses that automatically locate the direction of the sun, and other devices are widely used on aircraft. In spite of the high quality of these automatic devices, they no longer solve navigation problems with sufficient precision, reliability, or speed at the velocities of contemporary flight. The increased velocities, altitudes, and distances of flight so complicated the guidance work of the crew that the precision of aircraft guidance declined notice-

ably.

Future increases in the velocities, altitudes, and ranges of flight will require not only the perfection of existing means of aircraft guidance, but also the creation of entirely new devices which solve aircraft-guidance problems with speed and precision. This is especially necessary in connection with the extensive recent development of various types of pilotless flying craft.

The chief task in the development of navigation technique will obviously be the creation of autonomous automatic methods, i.e., methods that are independent of ground installations and the conditions of flight and also exclude the influence of artificial disturbances. The astronomical methods of aircraft guidance offer the greatest promise in this respect. When automated, they can provide guidance for aircraft and rockets at any range, altitude, and speed and eliminate one of the basic inadequacies of the existing methods--the great losses of time in measurement and computation. Approximately 5 min are required for the crew to determine the position of an aircraft from two astronomical position lines. At a flight speed of 20 km/min, the aircraft will be 100 km removed from the point at which the measurements were made by the time the computations are completed and the astronomical position lines are entered on the map. The question arises: who wants to know what point far in the rear was occupied by the aircraft when it is necessary to establish its position at a given instant?

The reply to the question as to where the airplane is now must be immediate and exact. And even this is possible at the present level of development of science and technology. It is necessary for this purpose to automatize not only the process of measurement of the aircraft's altitude; the computations must be carried out by automatic computers rather than by a human, and the results of the calculations must be fed continuously to special indicators on the instrument panel in the navigator-and-pilot cabin in the form of the heading and coordinates of the aircraft.

Thus the future development of the astronomical methods will be directed toward the creation of automatic devices that make it possible to determine the position of the aircraft and the direction of its flight, and to reckon the course over which it has traveled. Let us consider briefly the prospects for the development of the basic astronomical methods of aircraft guidance.

1. Contemporary aeronautical sextants permit determination of the altitude of only a single celestial body. To determine the position of an aircraft by the prevailing method it is necessary to have at least two position lines, i.e., to measure the altitudes of two celestial bodies. To shorten the time of measurement and increase the precision of determination of the aircraft's position, we need an instrument that automatically measures the altitudes of two or three celestial bodies and indicates the result continuously in the form of certain navigation elements.

Devices can be created that automatically determine the position of an aircraft from altitudes of several celestial bodies measured at different times, or even from the measured coordinates of only a single body. Such devices are known as celestial orientators. Individual models of celestial orientators have already been built, and the first experiments in their use have given good results.

Together with inertial aircraft-guidance systems, celestial orientators may, in the future, become a basic method of assuring high-precision aircraft guidance under varying conditions in the navigational environment.

2. Contemporary remote astrocompasses with automatic photoelectric tracking systems determine the course of an aircraft only by the sun. But aircraft fly by night as well as by day. Therefore it will also be necessary to have astronomical course instruments that will work reliably at any time of day. This is particularly important for long-distance flights lasting 12 to 16 hours and longer. Such devices may be sidereal astrocompasses that automatically track a certain preselected star by means of a photoelectric tracking system, with remote transmission of true-course values both to the instrument panel in the aircraft's cabin and into the automatic-pilot system to correct the course guidance of the aircraft, particularly during long flights. These problems may also be solved in celestial orientators.

The possibility of tracking stars by day is of great practical interest. Stars that are readily visible to the unaided eye at night are indistinguishable by day against the background of dispersed skylight. The brightness of the background is determined by the position of the sun. The background brightness is highest in the direction of the sun and significantly lower in other sectors of the sky. Special astronomical instruments having telescope tubes with very small fields of view (a few minutes of arc) may be used to observe stars by day in sectors of the sky of moderate brilliance.

The brightness of the sky background also declines considerably with increasing altitude of observation. At 20 km, the background-brightness sky is about one twenty-fifth or one thirtieth of that at an altitude of 3 km. Thus the conditions of daytime star observation improve significantly with increasing flight altitude. Very bright stars can be observed in daytime with the naked eye even from low altitudes.

Below we present a list of altitudes at which stars of different brightnesses are visible in the daytime with the sun about 30° distant from them:

Stellar magnitude	-1	0	1	2	3
Altitude (km)	3	10	20	35	55

The magnitudes of aerial-navigation stars range from -1.6 to 2.1. Therefore many of them can be observed in the daytime with the aid of ordinary aeronautical astronomical instruments during flight at altitudes of 10 to 20 km. At lower flight altitudes, only Sirius with its stellar magnitude of -1.6 will be visible in the Northern Hemisphere.

At low flight altitudes, a special apparatus with a telescope having a field of vision of a few minutes of arc will be needed to locate stars. In this case, having set the tube of the telescope on the chosen star by reference to its position coordinates (at a sufficient angular distance from the sun), we may observe the star to keep it in the field of vision and thereby determine the navigation elements and position lines. The shooting of a second star or the sun will permit us to determine the position of the aircraft even by existing methods.

Daytime observation of stars can be effected by making use of their infrared radiation, since the emission spectra of many stars have maxima in the infrared region. The use of photoelectric cells sensitive to infrared radiation will broaden the opportunities for daytime observation of the stars.

5. The creation of astronomical aeronautical computing devices.

The tables (AAE, TWA, TVAZ, etc.) in use by our country's aviators are much simpler and more convenient than the corresponding tables in the hands of aviators abroad. But even these require much time

for computation of the elements of the position lines and position of the aircraft, and this is their principal shortcoming. The solution to this problem can obviously be found in the creation of computing devices which relieve the navigator of such calculations. Such devices may be built in the very near future on the basis of electronic computers that perform tens and hundreds of thousands of operations per second.

Aircraft electronic computers must be of the general-purpose type, i.e., they must process data obtained from various instruments and issue the final result to an indicator or a control device.

The development of the astronomical methods will not take its own direction. On the contrary, as these methods are automated, various devices operating on different principles will be unified, and integrated navigation systems will be created that automatically solve all navigation problems in flight and, like automatic navigators, indicate the position of the aircraft directly on a map at any moment of the flight.

The prospect of the emergence of aircraft beyond the limits of the atmosphere now poses new navigation problems. It will obviously be impossible to employ aeronautical instruments that operate on atmospheric pressure (airspeed indicators, barometric altimeters, rate-of-climb indicators) outside the Earth's atmosphere.

The method of reckoning course by the use of compass and airspeed readings to obtain the position of the aircraft produces sig-

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significant errors due to the low precision of the initial data--particularly those from the airspeed indicator. Devices which effect automatic computation of course by integration of air speed and wind velocity over the time of flight also give large errors due to the errors in the determination of air speed and wind velocity.

To provide for the navigation of aircraft under any and all flight conditions--even extraatmospheric conditions--and to elevate the precision of aircraft (rocket) guidance, fundamentally new methods of solving navigation problems have been sought in many countries during the past few years. One of these is the design of the so-called inertial navigation system. The operating principle of this system consists in the measurement of the accelerations of the aircraft or rocket from the moment of takeoff or flight past some reference point. Integration of the accelerations produces the aircraft's speed, and a second integration produces the distance traversed and with it the aircraft's coordinates. In the inertial navigation systems, the accelerations are measured not with respect to the Earth, but with respect to the space of the "fixed" stars, or, as it is termed, "inertial space" (hence the term "inertial navigation").

The inertial navigation system possesses a great advantage in that the position of the aircraft or rocket is determined without reference to any ground points and without natural or artificial radiation.

This system requires no source of radiation whatever and does not itself emit signals of any kind. All measurements are carried out within the aircraft.

In an inertial navigation system, the aircraft's position coordinates or those of the rocket with respect to the "fixed" stars are converted into coordinates with reference to the Earth by a special computing apparatus.

The inertial system possesses high precision in its navigation-determinations, and this precision is not a function of any external factors. To increase the precision of such a system, provision is made for the correction of cumulative errors either on the principle of the celestial orientator or by means of radar (using the Doppler effect).

Extensive automation of navigational methods, including astronavigational methods, is the most important requisite for the guidance of aircraft and rockets at contemporary flight velocities. It is even more vital for cosmic flight velocities.

2. The Use of Radio Astronomy in Aviation.

The celestial bodies and the possibility of their use for aircraft guidance were discussed above as conditioned by their optical visibility. A new branch of science and technology has appeared and undergone rapid development in recent years: radio astronomy, the application of which to aviation is opening new possibilities for

aircraft guidance. Stemming from study of the radio-frequency emission of the sun and moon, radio astronomy makes it possible to observe celestial bodies through fog and clouds and at any time of day, regardless of whether light is received from them.

We know that light waves compose a small part of the vast range of electromagnetic waves. The electromagnetic waves encompass all forms of radiation beginning with the gamma rays and including sound vibrations and vibrations of still lower frequency. A fundamental characteristic of any vibration is its wavelength. Light waves have wavelengths from 0.38μ (violet rays) to 0.76μ (red rays). The radio waves embrace a much wider range of wavelengths from 1 mm to 3 km and more (Fig. 103).

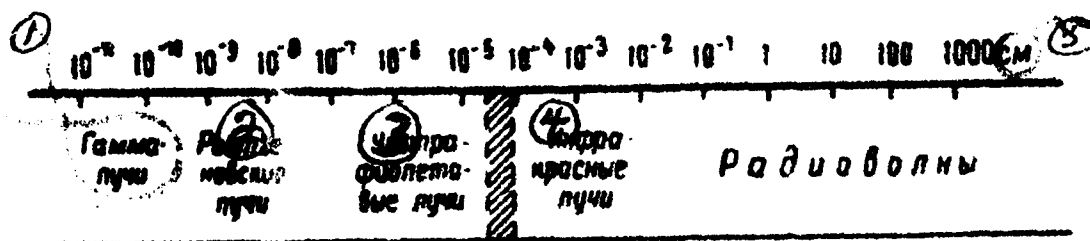


Fig. 103. Scale of electromagnetic waves.

- 1) gamma rays; 2) x-rays; 3) ultraviolet rays; 4) infrared rays;
5) radio waves; 6) cm.

Electromagnetic waves are emitted by any heated body, with the length and energy of the wave depending on the surface temperature of the emitting body. The temperature of the surface layer of the sun is approximately 6000° ; the temperature of the surfaces of the majority of stars ranges from 4500 to $10,000^{\circ}$. The moon and planets

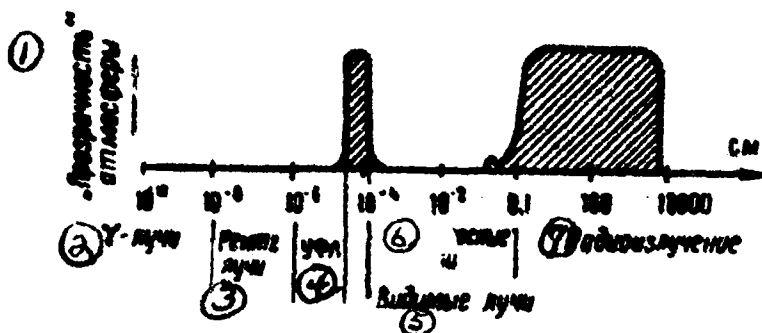


Fig. 104. "Transparency" of the Earth's atmosphere for electromagnetic waves.

1) "transparency" of atmosphere; 2) gamma-rays; 3) x-rays; 4) UV; 5) visible rays; 6) infrared rays; 7) radio-frequency emission.

possess low plus and even subzero temperatures, but even these are sufficient for the emission of radio-frequency waves.

The sun and stars radiate electromagnetic waves of varying energy in almost all regions of the spectrum, although we can detect far from all of them, since the Earth's atmosphere absorbs the greater part of the electromagnetic waves emitted by the celestial bodies. It will be seen from Fig. 104 that the visible rays are almost all passed by the atmosphere, while the ultraviolet and infrared rays are transmitted only in part. Cosmic radio-frequency emission arrives at the Earth in a wider range of wavelengths beginning with the longest passed by the ionosphere*, i.e., waves from 15-25 mm long, and extending to the millimeter waves.

* The ionosphere is the upper part of the atmosphere, which contains ions and free electrons in considerable quantity. The ionosphere begins at an altitude of 60-80 km and extends to 400 km and higher.

Thus it is possible to observe the celestial bodies not only through the "optical window", which transmits the visible and some of the ultraviolet and infrared rays, but also through a "radio window", which confers preference to radio-astronomical observations over the optical observations.

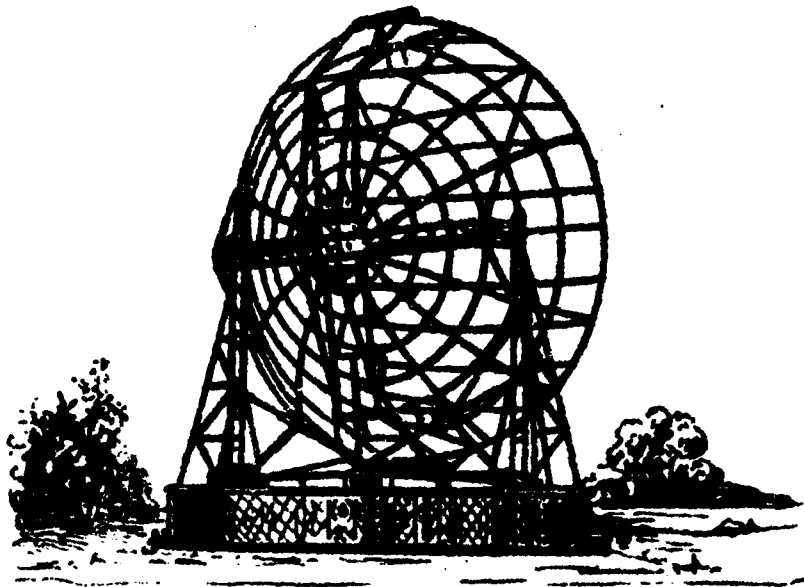


Fig. 105. Parabolic antenna for reception of cosmic radiation at centimeter wavelengths.

Radio-frequency emission from sources outside the Earth was first observed in 1931. But since the power of radio-frequency cosmic radiation is, as a rule, quite low, the development of radio astronomy became possible only after the creation of sensitive radio receivers and large directional antennas--the so-called radio telescopes. The larger the antenna, the higher will be the resolving

[power of the radio telescope, i.e., its capacity to sense separately]
sources of radiation that are located close together on the celestial sphere.

The antennas may be of various configurations, but multi-dipole cophasing antennas are given preference in practice for the reception of meter waves and parabolic reflectors for centimeter-wave reception (Fig. 105).

The use of radio telescopes for the guidance of aerial and marine vehicles is prohibited by the great size of their antennas. This obstacle is being overcome at the present time, and marine radiosextants (Fig. 106) that permit reception of the radio-frequency emission of the sun and other celestial bodies have already been built. The radiosextant's parabolic antenna is 78 cm in diameter. Such a radiosextant makes it possible to determine the sun's coordinates with an error of 1 to 2'.

Aircraft radiosextants are also being designed. They are reminiscent, in principle, of a radar station with automatic target tracking. Like the radar station, they have an antenna system, a receiver with amplifier and a system for automatic tracking of the sun in azimuth and altitude (angle of elevation). Receiving the radio-frequency radiation of the sun, the radiosextant follows its position on the celestial sphere continuously. The measured solar coordinates are transmitted to a computer, to which other navigation data may also be supplied: the bearing of the aircraft, its]

flight speed, etc. The computer may automatically determine the coordinates of the aircraft's position from these data. The radiosex-

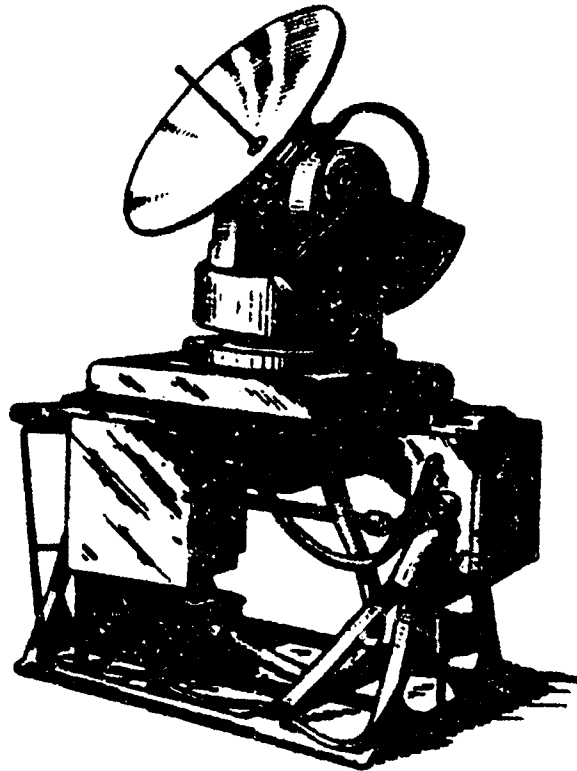


Fig. 106. Marine radiosextant.

tant model illustrated in Fig. 107 works on the 1.9-cm wavelength, weighs 45 kg and has an antenna-system diameter of 60 cm. The antenna is mounted on a platform which is stabilized gyroscopically, thus permitting the maintenance of its position with reference to the sun and, consequently, a reduction of the error of measurement due to the oscillations of the aircraft. The precision of determination of the sun's position with such a radiosextant is about 2'.

Work toward the creation of radio-astronomical apparatus and further exploration of the Universe proceeds without interruption. That remarkable discovery of the great Russian scientist A. S. Popov--radio--has found a new use: it has become a powerful tool in the investigation of cosmic bodies. Thanks to the efforts of scientists in many countries, the sensitivity of the modern receivers used in radioastronomy is so great that they can pick up radio-frequency radiation whose flux density is hundreds of millions of times smaller than that of the Moscow television center at a distance of 50 km.

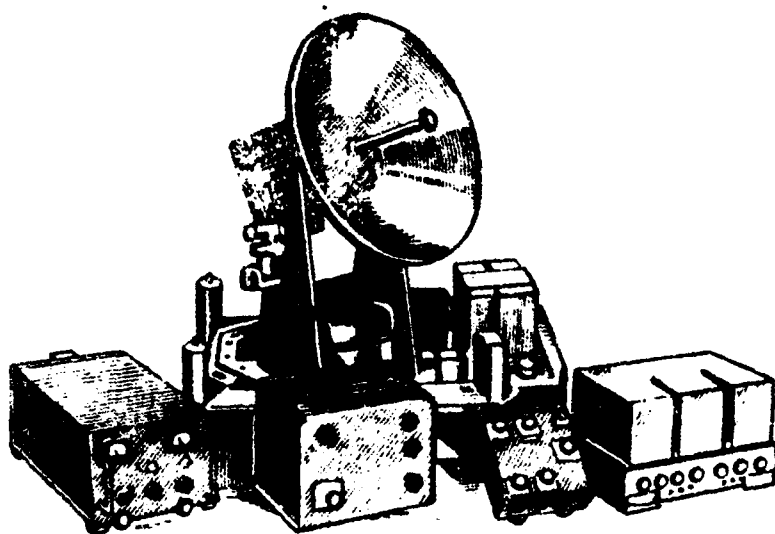


Fig. 107. Aircraft radio sextant (American).

Radio-astronomical studies of the sun have made it possible to establish that the solar radio emission occurs in a range of wavelengths from 8 mm to 12 m, and that their power varies. It is mil-

lions of times greater in periods of elevated solar activity (appearance of sunspots, chromospheric flares, etc.) than the power of the radio-frequency radiation of the "quiet sun." Isolated "outbursts" and "splashes" of radio-frequency emission cause scattered temporary interruptions of short-wave radio communication and intense radio noise.

The radio-frequency emission of the moon has been studied thoroughly on the 1.25-cm wavelength. It has been ascertained that it is quite independent of the moon's phase and originates in subsoil layers at a depth of about 0.5 m.

Radio-astronomical studies have also been made for certain planets. Thus the radio emission of Venus indicated that the temperature at its surface is not 50° as assumed previously, but over 100° ; the radio emission of Jupiter has its maximum power at the 8-m wavelength. Preparations are presently being made for the reception of radio signals from other planets as well; foremost among these are Mercury, Mars, and Saturn.

Study of the radio emission of the galaxy has revealed regions of elevated radio emission in the constellations Cygnus, Cassiopeia, Taurus, and certain others. The flux of these radio emanations is tens of billions of times greater than the luminous flux of the brightest star, Sirius. Faint nebulosities or supernova flareups have been observed at the positions of a number of these powerful sources.

It is believed that the radio-frequency emission of the galaxy is governed by free electrons, ionized interstellar gases, and isolated sources--the debris of supernova flareups. Random radiation from other galaxies (nebulae) is superimposed on this radiation.

Thus observations of the radio-frequency emission of cosmic objects, together with data on the distribution of the sources of radio emission in space, provide us with information on the nature of these sources and the processes unfolding in them.

Radar astronomy, which is concerned with study of radio waves transmitted from the Earth and reflected from cosmic objects (the moon, meteor trains) is an autonomous field of radio astronomy. Radar contact with the moon, i.e., the transmission of a radio signal to the moon and the detection of the reflected signal, made possible the first determination (from the elapsed time before the arrival of the reflected signal) of the distance to a celestial body in the history of mankind by the use of experimental means rather than the usual method of observation and computation.

Radio astronomy in aeronautics offers new possibilities for the creation of autonomous aircraft-guidance systems.

3. Flights into Outer Space.

The day 4 October 1957 passed into history as the beginning of human conquest of cosmic space.

The launching of the first artificial earth satellite was preceded by a tremendous amount of work on the part of Soviet scientists, engineers, and workers in the creation of an intercontinental ballistic rocket, which was first tested in August of 1957. The flight of the ballistic rocket was made at an altitude of several hundred kilometers. No flying device created by man had previously attained such an altitude. Traversing a tremendous distance in a short time, the rocket fell exactly into the designated area. This confirmed the correctness of the choice of its design and the flight calculations.

In contrast to airborne rockets, the ballistic rocket is launched vertically and its flight controlled not over the entire trajectory, but only in an initial, relatively small section (about 400 km), after which the rocket flies like an ordinary artillery projectile (Fig. 108). It may reach a maximum altitude of up to

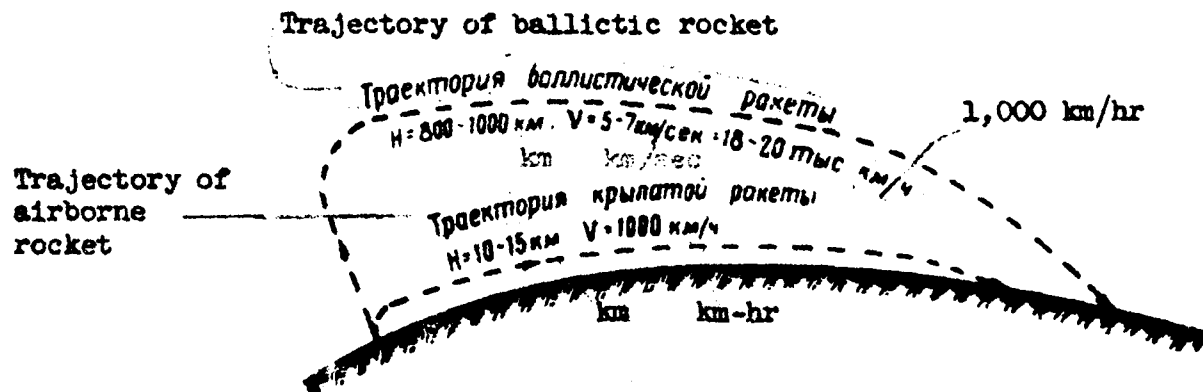


Fig. 108. Flight trajectories of ballistic and airborne rockets.

1000 km and flies at a velocity of about 20,000 km/hr, with a range

in excess of 8000 km. The speed of airborne rockets (e.g., the Am-

erican "Snark" rocket) is relatively low--about 1000 km/hr--and their flight altitudes range from 10 to 15 km.

The airborne rocket is controlled by an automatic pilot and other automatic devices over its entire flight trajectory. The automatic pilot that guides such a rocket along its course works in conjunction with astronomical guidance systems. Astronomical course instruments assist in correcting the errors accumulated under the conditions of its flight along the trajectory by determining automatically the position of the rocket with reference to celestial bodies (stars). Unlike ballistic rockets, airborne rockets are easily vulnerable to antiaircraft weapons.

The creation of the ballistic rocket marked a great accomplishment on the part of Soviet science and technology and represented the last practical step leading up to the launching of artificial earth satellites. In accordance with the program of operations of the third International Geophysical Year, which was initiated on 1 July 1957 and continued to 31 December 1958*, three artificial satellites of the Earth were launched in the Soviet Union: on 4 October and 3 November 1957 and on 15 May 1958.

The launching of the first artificial satellite demonstrated to all progressive humanity the superiority of Soviet science and tech-

* Research under the program of the International Geophysical Year was continued to 31 December 1959 under the designation "International Geophysical Collaboration 1959."

nology over the bourgeois. It is well known that the artificial earth satellite launched in the USA on 31 January 1958 weighed only 14 kg; the mean height of its orbit was about 1300 km and its orbital velocity less than 7 km/sec. Further repeated attempts by the Americans to launch satellites comparable to the Soviet satellites were not crowned with success in the recent International Geophysical Year.

The successful launching of the satellites is not to be regarded as the accomplishment of any single branch of science. This was a triumph of all Soviet scientists and technologists--the result of the growth of our entire industrial capacity and the whole socialist economic, social, and governmental system as created under the leadership of the Communist Party.

The successful solution of problems in the design of powerful rocket engines and the fuels which they require, as well as in the development of highly complex automatic devices, is testimony to the fact that Soviet science has surged forward to first place in the world in many departments. This is acknowledged not only by our friends, but by our enemies as well.

The first Soviet artificial earth satellite (Fig. 109) took the form of a sphere 58 cm in diameter weighing 83.6 kg. In it were installed two radio transmitters which broadcast signals continuously at 7.5 and 15 m. The satellite was released by its rocket vehicle at an altitude of about 900 km above the Earth's surface and guided

into an orbit in which a linear velocity of 8 km/sec (about 29,000 km/hr) was imparted to it. The satellite revolved about the Earth in an elliptical orbit inclined 65° to the plane of the equator (Fig. 110). During the first few days, one revolution was completed in 1 hr 36.2 min.

The "little Soviet moon", as the satellite was named by foreign newspapers, was picked up by radio stations and was visible in the light of the rising and setting sun. During the 94 days of its existence, the satellite completed about 1400 revolutions about our planet and traversed a distance of about 60,000,000 km.

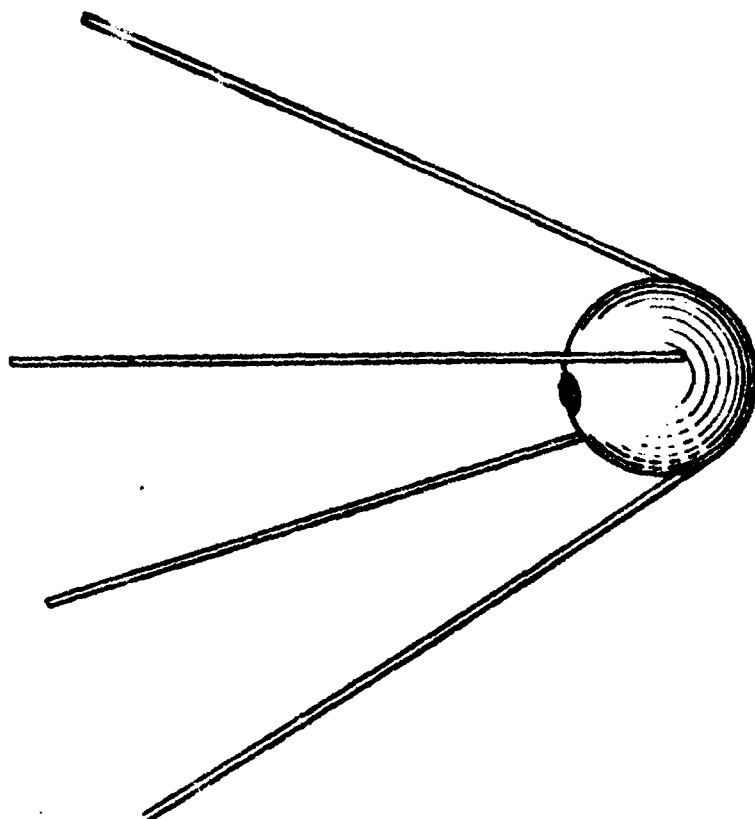


Fig. 109. General appearance of first Soviet artificial earth satellite.

The second artificial satellite entered orbit on 3 November 1957. It represented the last stage of the rocket vehicle and carried containers with scientific apparatus (Fig. 111). The satellite's payload (the weight of the apparatus, the experimental animal, and the sources of electric power) was 508.3 kg.

The maximum distance of the second satellite's orbit from the Earth's surface was over 1500 km, and its orbital velocity was about 8 km/sec. During its lifetime, it completed 2370 revolutions about our planet and traveled a distance of over 100,000,000 km.

The launching of the third Soviet artificial earth satellite was a glittering new achievement that reaffirmed the leading role of our country in the struggle for mastery of the cosmos. The satellite is an automatic scientific laboratory in the fullest sense of the term; it is conical in shape, with a base diameter of 1.73 m and a height of 3.75 m (without counting the projecting antennas); the satellite weighed 1327 kg and attained an altitude of 1880 km.

The third Soviet artificial earth satellite lasted considerably longer than the first two. Its total number of revolutions and the distance traveled were several times greater than in the case of the first two satellites.

The possibility of flight into cosmic space was first given a scientific basis as long ago as the end of the last century by the Russian Scientist K. E. Tsiolkovskiy, the founder of modern rocketry. He is said to have uttered the words "I believe that many of you will

witness the first extraatmospheric voyage." His dreams of navigating outer space with the aid of rockets have now been successfully

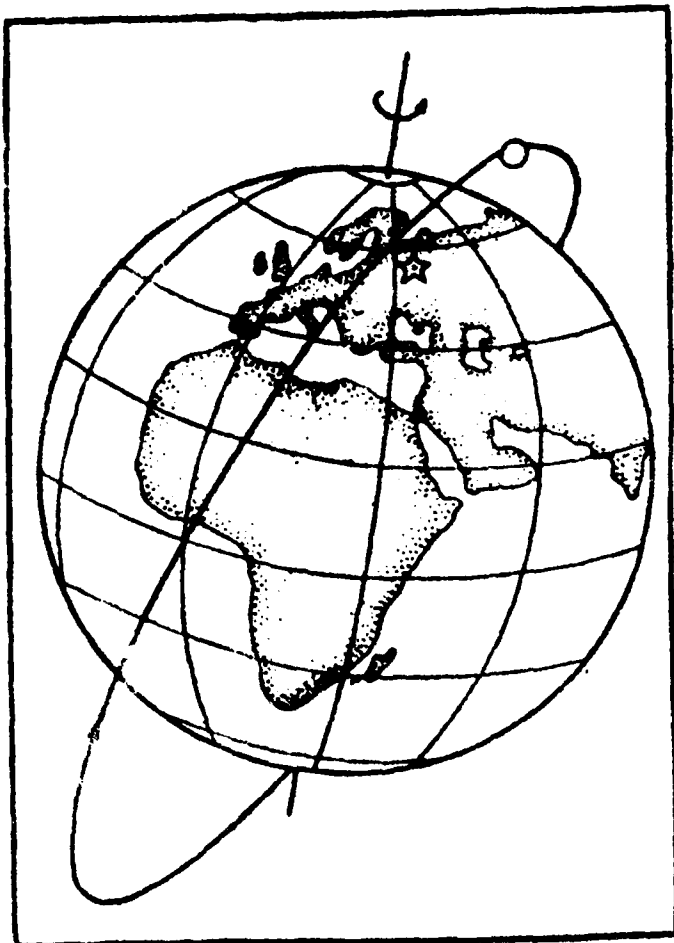


Fig. 110. Orbit of the first artificial earth satellite.

brought to life.

The creation of an object capable of overcoming the attraction of the Earth and escaping into interplanetary space is based on Newton's laws of celestial mechanics, which apply equally to all celestial bodies, including those which have been created artificially.

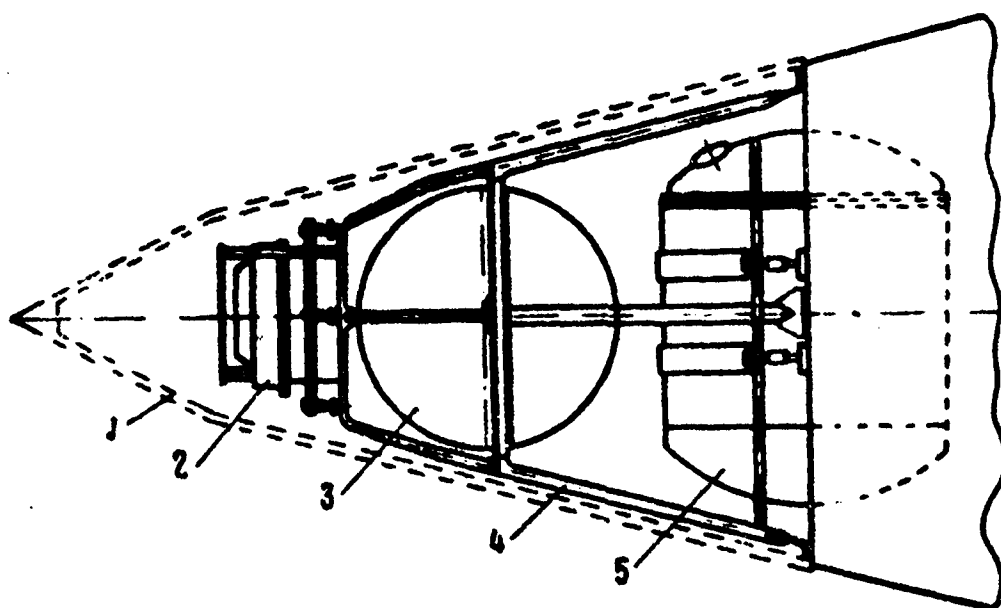


Fig. 111. Arrangement of apparatus in second Soviet artificial earth satellite:

1--Protective shell, thrown off after satellite has been guided into orbit; 2--device for study of ultraviolet and infrared solar radiation; 3--spherical container with apparatus and radio transmitters; 4--Structural framework for attachment of apparatus; 5--hermetically-sealed cabin for experimental animal.

If there were no force of gravitational attraction and no air resistance, any thrown object would move at a constant rate in a straight line on its own inertia and therefore progressively recede from the Earth into outer space. The forces of terrestrial gravitation and air resistance prevent such motion of the object and bend its path with the result that the object falls to earth. The higher the initial velocity of the thrown object, the farther it will fly from

the point of projection, other conditions remaining the same.

To offset the gravitational attraction of the Earth and make the object revolve about it in a circular orbit, it is necessary to impart an initial velocity of 7.9 km/sec (the circular velocity) to it at the surface of the Earth. In this case the object would move at constant velocity along a circle having its center at the center of the Earth. Since the resistance of the air will gradually reduce its velocity, the rocket will gradually descend and fall to earth after a certain time. As the altitude is increased, the velocity of the circular motion will decrease slightly. Thus it should be 7.8 km/sec at an altitude of 200 km, 7.6 at an altitude of 500 km, 7.3 at an altitude of 1000 km, 6.9 at 2000 km, and 5.9 km/sec at 5000 km, etc.

As the initial velocity at the Earth's surface is increased from 7.9 to 11.2 km/sec, the rocket (satellite) will move along an elliptical orbit one of whose foci is located at the center of the Earth. Here the ellipse becomes more and more elongated as the velocity diverges from the circular velocity. Thus the rocket reaches halfway to the moon at a velocity of 11 km/sec, and at 11.1 km/sec it passes beyond the moon's orbit, remaining a satellite of the Earth.

At a velocity of 11.2 km/sec (the parabolic velocity), the ellipse breaks open to become a parabola. This is the limiting velocity for an artificial satellite; the rocket recedes to infinity

(Fig. 112).

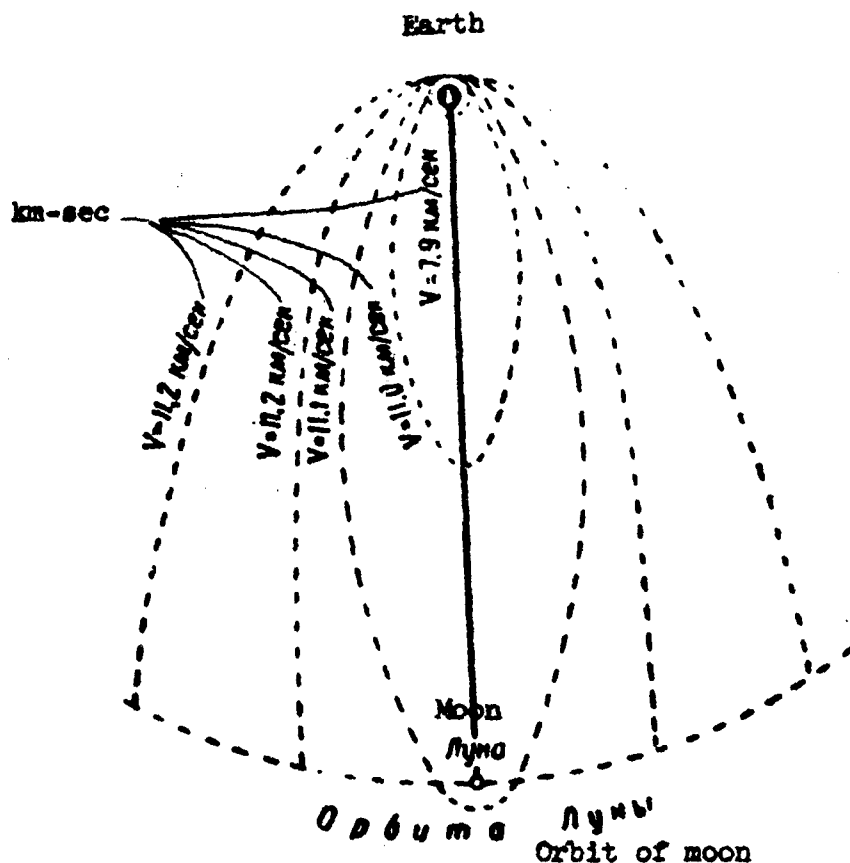


Fig. 112. Shape of rocket orbit as a function of launching velocity.

The period of revolution of a satellite about the Earth depends on the altitude at which it moves and is determined by the third law of Kepler. If the satellite's orbit is not circular, but elliptical, the period of revolution must be computed from the major semiaxis of the ellipse (Fig. 113). The length of the minor semiaxis does not influence the satellite's period of revolution; its velocity at the moment when it crosses an end of the minor axis of the ellipse is equal to the circular velocity.

The greater the altitude of a satellite, the longer will be its

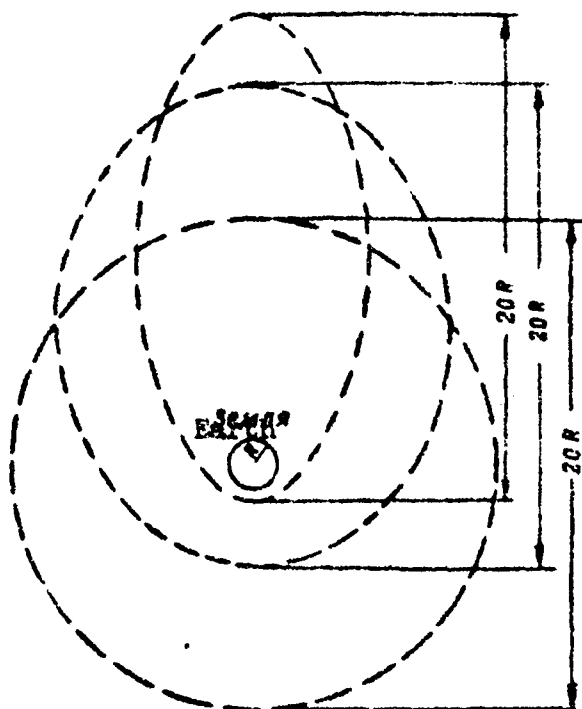


Fig. 113. The major axes of the orbits are equal: the periods of revolution of the satellites along them are identical.

orbit; the gravitational attraction of the Earth will be weaker, and this means that both the centrifugal force and the velocity of the satellite will be smaller, while the period of revolution will be longer. The dependence of the period of revolution of a satellite in a circular orbit on its altitude is presented in the table below:

Altitude in circular or- bit, km	Maximum alti- tude in ellip- tical orbit (with minimum altitude of 200 km), km	Period of revolution about Earth	Number of revo- lutions per si- dereal day
--	---	---	--

0	0	1 ^h 24 ^m 25 ^s	17
558	916	1 35 44	15
2,700	5,200	2 23 36	10
8,040	15,880	4 47 13	3
35,810	71,420	23 56 04	1

The moon is 384,000 km distant from the Earth, so that its period of revolution about the Earth is approximately four weeks.

Unless the satellite revolves in the plane of the Earth's equator and its period is equal to the period of rotation of the Earth, the projection of its trajectory onto the earth's surface will change continuously. The period of revolution of the first satellite was initially 96.2 min. Due to the rotation of the Earth about its axis, the projection of the satellite's motion onto the Earth's surface passed over different regions, shifting through about 24° of longitude in each revolution. At the latitude of Moscow, each successive spiral passed about 1500 km west of the preceding, and this shift amounted to about 2500 km at the equator.

The plane of the first satellite's orbit was inclined 65° to the plane of the equator, so that the path of the satellite passed

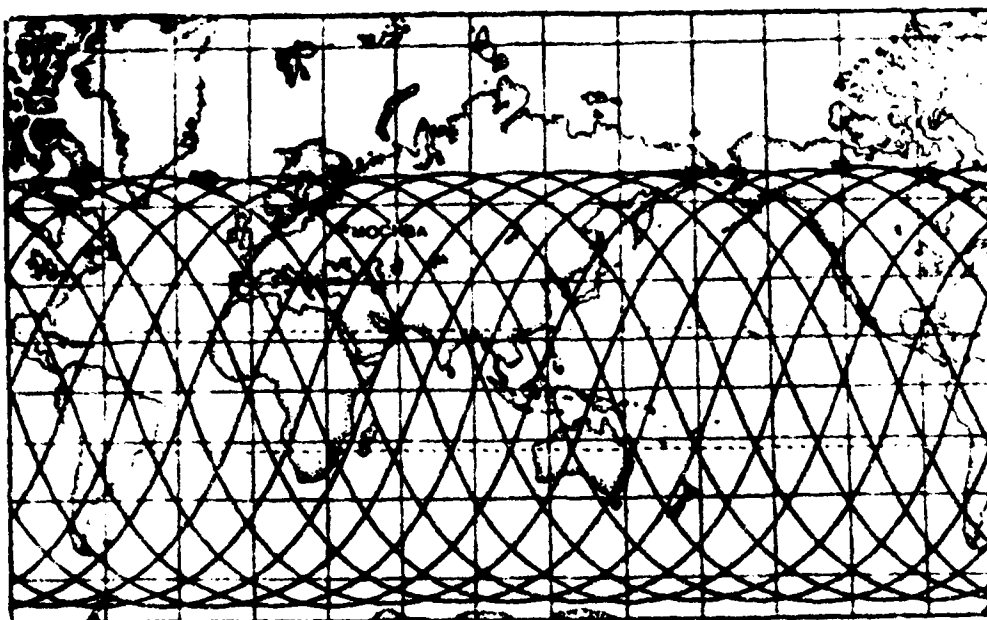


Fig. 114. Scheme of motion of first Soviet artificial earth satellite in one day.

over the regions of the Earth situated approximately between the Arctic and Antarctic Circles. Due to the rotation of the Earth about its axis, the inclination of the path to the equator differed from the inclination of the orbital plane. Entering the Northern Hemisphere, the path intersected the equator at an angle of 71.5° , going northeast. Then the path gradually turned increasingly eastward, becoming tangent to the parallel at 65° N and turning southward to intersect the equator in a southeastward direction and enter the Southern Hemisphere. There it touched the parallel at 65° South Latitude, turned north and again entered the Northern Hemisphere (Fig. 114).

The basic factor that limits the lifetime of artificial earth satellites and results in their dropping to earth is the resistance of the atmosphere. The orbits of the recently-launched artificial satellites of the Earth pass through extremely rarefied layers of the atmosphere where the density is no greater than one four-billionth of the surface density of the air, and the drag does not exceed two grams per square meter of cross-sectional area, even at the lowest point in the orbit. Nevertheless, even this level of atmospheric drag has an important influence of the motion of the satellites.

Under the influence of the atmosphere's resistance, some of the satellite's kinetic energy is constantly being lost, with the result that its orbit continually becomes shorter and approaches the Earth's surface and its period of revolution declines. Due to the deceleration of the satellite, the maximum height of its orbit (apogee) falls off much more rapidly than the minimum height (perigee), so that the satellite's orbit gradually approaches the circular. As the perigee is depressed, the atmospheric drag naturally increases, and the process of reduction of the satellite's period and depression of its orbit become more rapid until the satellite enters the dense layers of the atmosphere and burns up. At this time the period of revolution attains its smallest, critical value, which is approximately 87.75 min.

Thus the lifetimes of artificial earth satellites are governed by two basic factors: the magnitude of the resistance offered by

the atmosphere and the initial value of the period of revolution.

The lower the deceleration and the longer the initial period of revolution, the longer will the satellite continue to exist.

The resistance of the atmosphere to the motion of an artificial earth satellite depends, in turn, on the altitude of the orbit's perigee and on its aerodynamic and ballistic properties: the so-called sectional density, i.e., the amount of the satellite's weight associated with a unit area of its cross section, is a factor of the first importance in determining the latter.

The lifetime of a satellite may vary through a very wide range with variation of the perigee altitude and the sectional density. Thus an artificial earth satellite with a nearly circular orbit having a perigee altitude of about a thousand kilometers would persist for a practically indefinite period.

With a perigee altitude of 500 km, its lifespan would run to two to seven years, depending on the value of the sectional density, and with a perigee altitude of 150-160 km the satellite would be able to complete only about one revolution about the Earth.

Sectional density exerts a less important influence on the lifetime; when the ratio of the weight of the satellite to its cross-sectional area is reduced by a factor of ten, its lifetime will also be shortened by a factor of approximately ten.

It is the factors enumerated above that determined the varying character of the decline in the periods of revolution of the first,

second, and third Soviet artificial earth satellites and their differing lifetimes. Thus the first Soviet satellite and its rocket vehicle had equal perigee altitudes and periods of revolution (96.2 min) when they went into orbit. Due to the different values of sectional density for the satellite and the rocket vehicle, however, the daily decrements in their periods of revolution were unequal, amounting to 1.6 and 2.7 sec. As a result, the first satellite existed for 94 days, but its rocket vehicle for only 60.

The second Soviet satellite, which was constructed as an integral unit with its rocket vehicle, which was very similar aerodynamically and ballistically to the rocket vehicle of the first satellite and approximately the same perigee altitude, revolved about the Earth for 163 days. The longer persistence of the second satellite is accounted for by the larger value of its initial period of revolution. The period of revolution of the second satellite amounted to 103.7 min, i.e., 7.5 min longer than that of the rocket vehicle of the first satellite. With practically the same daily decrement from the initial period of revolution, it is natural that the second satellite arrived at the critical value of the period of revolution after a longer time than the rocket vehicle of the first satellite.

The third Soviet artificial earth satellite was placed into orbit with an initial perigee altitude approximately the same as those of the two preceding satellites, but with a longer initial period of revolution equal to 105.95 min. This circumstance alone was respon-

[sible for the longer lifetime of the third satellite and its rocket vehicle as compared with its predecessors.]

It is possible to create a satellite that will be stationary with respect to an observer on the Earth, changing its position only with respect to the stars. For this purpose, of course, it would be necessary to raise it to an altitude at which its period of revolution will be equal to the period of rotation of the Earth about its axis. If such a satellite were to move in the plane of the equator from west to east, its angular velocity of revolution would be equal to the angular velocity of rotation of the Earth about its axis, and it would be seen from the Earth at the same point in the sky at all times. Such a satellite is referred to as a stationary or "perpetual" satellite. Its altitude above the equator would be 35,810 km or 6.61 Earth radii.

As compared with other satellites, a stationary satellite possesses a number of attractive features. If such a satellite is manned, it would be easier for the crew to maintain communication with the Earth by means of directional radio or light signals. With the use of radar, such an earth satellite can be used for the purpose of aircraft guidance and to increase the range and stability of radio communication.

It is interesting to note that from such a satellite, our Earth would be seen as a stationary object with an angular diameter forty times that of the lunar disk as seen from the Earth.]

In order to generate the flight velocity necessary for the escape of an artificial Earth satellite or any other man-made object into the cosmos, it is necessary to employ the powerful multistage rockets whose creation was a concept proposed by K. E. Tsiolkovskiy. A ballistic rocket consisting of a liquid-fueled reaction engine, tanks for fuel (e.g., kerosene, alcohol) and the oxidizer necessary for combustion of the fuel (e.g., liquid oxygen, nitric acid) can develop a velocity as high as 3 to 4 km/sec. But velocities of 5 to 7 km/sec are necessary even for the flight of an intercontinental rocket. Even higher velocities are required for flight into the cosmos. In the multistage rocket, i.e., a rocket which itself consists of several rockets (engines), the exhausted engines and tanks are jettisoned one after another after launching, and the thus lightened rocket accelerated by the remaining motors to attain the predetermined flight velocity.

Artificial earth satellites launched into cosmic space have procured information on the nature of the cosmos and the phenomena prevailing therein that it would be impossible to obtain by any other means.

The mean value of the density of the atmosphere was determined as a result of the scientific investigations conducted with the aid of the three Soviet Earth satellites. It was found to be 5 to 10 times higher at an altitude of 226-228 km than the figures obtained earlier on the basis of theoretical evaluation of rocket experiments.

Important results were obtained in studies of the propagation of radio waves through the ionosphere and of the latter's structure.

It was found that the temperature of the ionospheric electrons is much higher than those of the neutral particles and ions at the altitude of the satellites.

A new form of radiation was discovered in studies in the region of cosmic rays. It develops that the Earth is surrounded by a kind of "halo" of high-speed electrons, which are held captive by the magnetic field of the Earth.

A living creature (the dog Laika) penetrated the cosmos for the first time in the history of humanity in the second earth satellite. The results of this biological experiment will serve as a point of departure for the penetration of interplanetary space by man.

The problems of complete hermetic sealing of satellites and instrument containers and of automatic temperature regulation have already been solved. Thus the temperature in the third Soviet satellite was maintained between 15 and 22° C during the entire period in which the apparatus was functioning.

The first, and later the second and third Soviet artificial earth satellites demonstrated to the entire world the feasibility of interplanetary voyages in the not too distant future. Such problems as the creation of "perpetual" artificial satellites revolving about the Earth at great altitudes with virtually unlimited lifetimes, the recovery of a satellite or part of it, etc., will be

solved first.

Solution of the problem of man in the satellite--study of all aspects of the conditions of life contingent upon the flight of man into cosmic space--will be of special importance.

The creation of artificial earth satellites that move in orbits approaching the moon is of extremely great interest.

The successful launching of a multistage cosmic rocket in the direction of the moon from the Soviet Union on 2 January 1959 presents fresh possibilities for the acquisition of knowledge of the Universe.

This event--the first of its kind in the history of mankind--aroused tremendous rapture all over the world and represented a new confirmation of the high level of development of our country's science and technology. The Soviet rocket attained a speed in excess of the second cosmic velocity. i.e., over 11.2 km/sec, passed near the moon on 4 January, and entered an orbit about the sun about 7 or 8 January, thus becoming the first artificial planet of the solar system.

The rocket carried a pennant with the crest of the Soviet Union and the inscription "Union of Soviet Socialist Republics, January, 1959."

The scientists, designers, engineers and workers who created the new rocket dedicated its launching to the XXI Congress of the Communist Party of the Soviet Union.

The rocket was launched vertically from the surface of the Earth. Its trajectory was gradually inclined from the vertical by the operation of a programming mechanism in the automatic system that guided the rocket. After passing the second cosmic velocity, the rocket moved along a hyperbola with respect to the center of the Earth. This trajectory was most tightly curved near the Earth, and straightened out with increasing distance from it. At the start of the rocket's travel along the trajectory, its velocity was highest; but it declined under the influence of the Earth's gravitational attraction with increasing distance. Thus the velocity of the rocket with respect to the center of the Earth was about 10 km/sec at an altitude of 1500 km, but had declined to 3.5 km/sec at an altitude of 100,000 km.

The rate of rotation of the radius vector connecting the center of the Earth with the rocket declined in inverse proportion to distance from the Earth's center in accordance with Kepler's second law. While this velocity amounted to approximately 252 deg/sec at the start of the motion, i.e., was over 15 times the angular velocity of the Earth's diurnal rotation, it was less than the latter velocity after about an hour. When the rocket neared the moon, however, the rate of rotation of its radius vector had been reduced by a factor of more than 2000.

These properties of the motion of the rocket along its trajectory determined the nature of its movement with respect to the sur-

face of the Earth (Fig. 115). As long as the rate of rotation of the rocket's radius vector was high by comparison with the velocity of rotation of the Earth, the projection of the rocket onto the Earth's surface moved eastward, with a gradual deviation to the south. Then the projection turned first to the southwest, and 6-7 hours after the launching, when the rate of rotation of the radius vector had become small, proceeded almost directly westward.

The rocket was launched at a time when the moon was in its last quarter, i.e., the moon was in front of the Earth from the viewpoint of the latter's orbital motion (Fig. 116).

As the cosmic rocket approached to a distance of a few tens of thousands of kilometers from the moon, the gravitational attraction of the moon began to exert a noticeable influence on the rocket's motion; this resulted in a certain deflection of the course of the rocket and gave rise to a local increase in the velocity of its flight near the moon. When the moon's orbit was crossed $3\frac{1}{4}$ hours after launching, the rocket was 5 or 6 thousand kilometers, i.e., about 3 lunar radii, away from it.

Could the rocket have struck the moon or become its satellite? Near the moon's surface, the circular velocity is somewhat higher than 1.7 km/sec, and at the distance to which the rocket first approached the moon, this first cosmic (for the moon) velocity is only about 1 km/sec. Near the moon, the rocket was traveling at a rate of over 2 km/sec. Therefore it could not become a lunar sat-

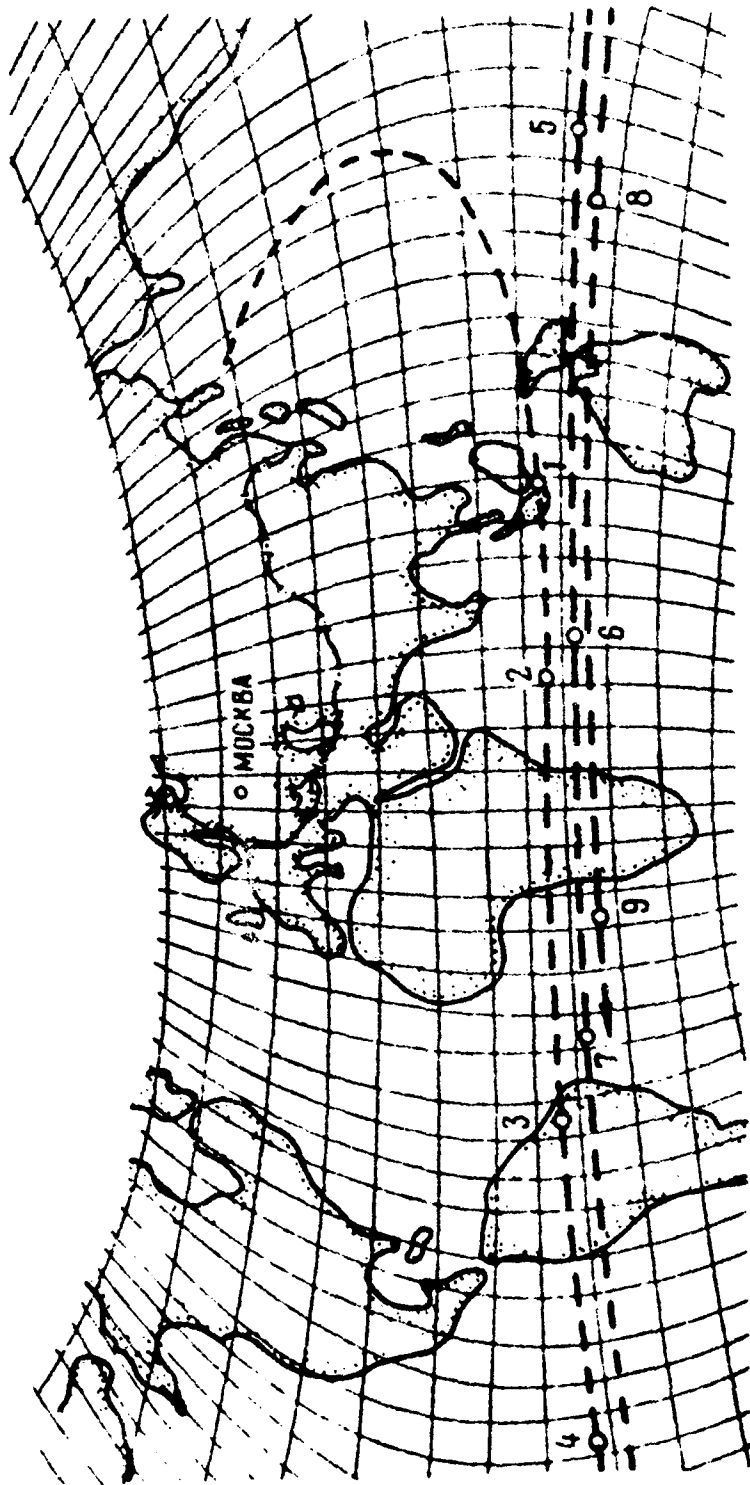


Fig. 115. Schematic trace of cosmic rocket. The numbers on the diagram correspond to successive positions of the rocket's projection onto the Earth's surface:

1-- 3^h 3 Jan, 100,000 km from the Earth; 2-- 6^h, 137,000 km; 3-- 13^h, 209,000 km; 4-- 19^h, 265,000 km; 5-- 21^h, 284,000 km; 6-- 5^h 59^m 4 Jan, 370,000 km, the moment of the closest approach to the moon; 7-- 12^h, 422,000 km; 8-- 22^h, 510,000 km; 9-- 10^h 5 Jan, 597,000 km.

ellite, much less impact its surface.

After its approach to the moon, the cosmic rocket continued to recede from the Earth and its velocity with respect to the Earth's

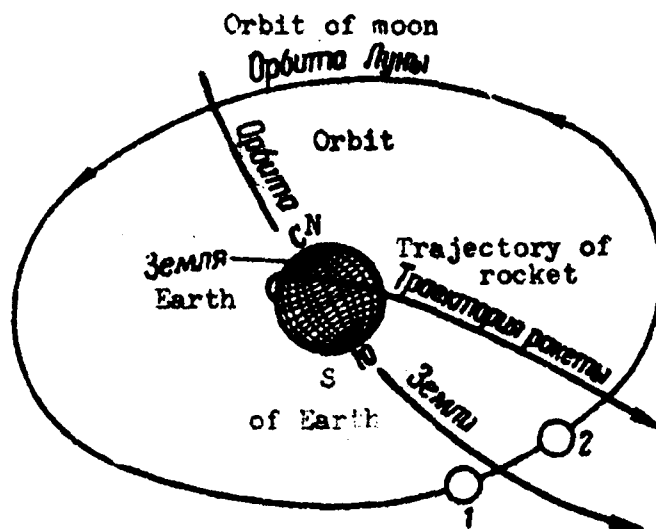


Fig. 116. Trajectory of approach of rocket to moon:

1-- position of moon at moment of launching;
2-- position of moon at moment of proximity to rocket.

center declined, approaching 2 km/sec. At a distance of 1 million km from the Earth, the influence of the Earth's attraction on the rocket was so weak that the rocket's motion became governed by the attractive force of the sun. The rocket was unable to overcome this force and therefore cannot escape from the solar system, since it would have been necessary for this purpose to impart to it an initial velocity of 16.7 km/sec--the third cosmic velocity.

Under the influence of the sun's gravitational attraction, the rocket emerged into the calculated orbit around the sun and became a perpetual satellite of it, just like the other planets (Fig. 117). The period of revolution of the first artificial planet about the sun is 450 days, i.e., approximately 15 months.

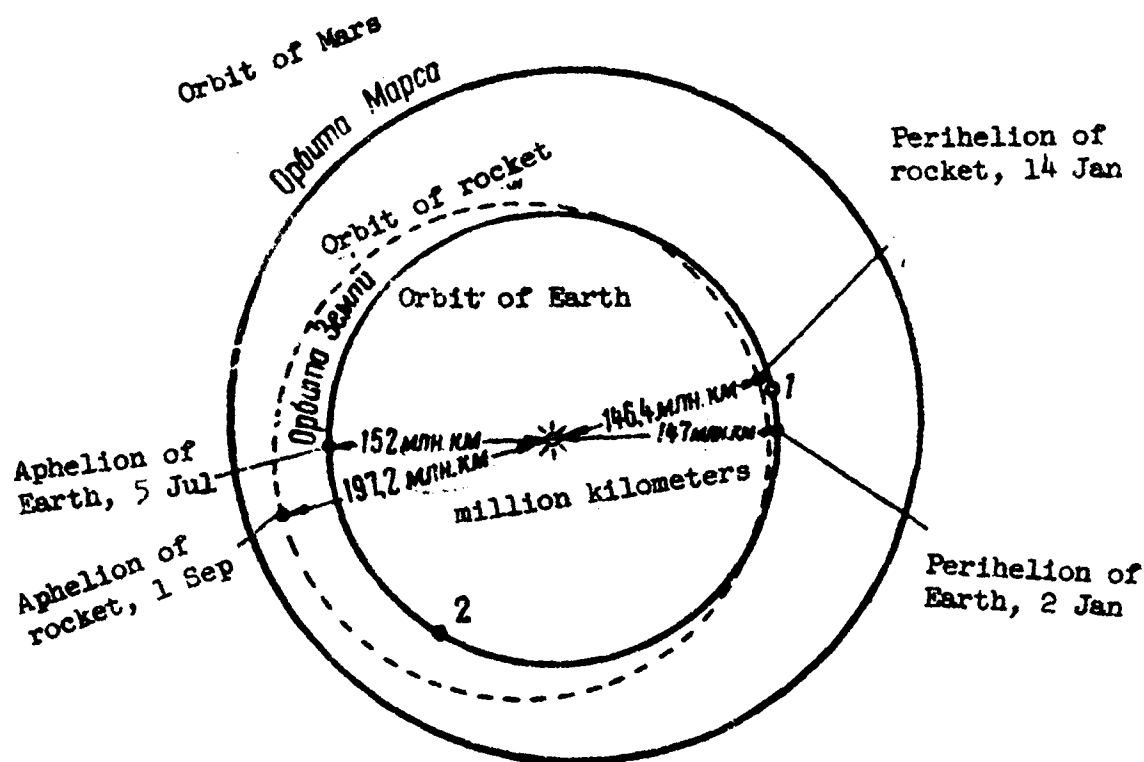


Fig. 117. Orbit of cosmic rocket about sun
(data are for 1959):

- 1-- Position of Earth in orbit on 14 Jan;
- 2-- position of Earth in orbit on 1 Sep.

At the time of entry of the rocket into orbit, its velocity with reference to the center of the Earth was in approximately the

[same direction as the velocity of the Earth in its motion about the sun. Since the velocity of the Earth is 30 km/sec, and the velocity of the rocket with reference to the Earth was 2 km/sec, the velocity of the rocket's motion about the sun at this time was approximately 32 km/sec. In other parts of the orbit, its velocity will vary, like that of any natural planet, in accordance with the laws of celestial mechanics.]

The launching of the cosmic rocket is of enormous scientific importance. The 1st stage of the rocket, which weighed 1472 kg without fuel, was equipped with a special container holding measurement apparatus for a large complex of scientific investigations: detection of the magnetic field and radioactivity of the moon, study of cosmic radiation outside the Earth's magnetic field, study of the corpuscular radiation of the sun, meteoric particles, etc. Several radio transmitters and a special apparatus that created a sodium cloud--an artificial comet--at an altitude of 137,000 km were installed on the last stage of the rocket to permit observation of its flight.

The orbit of the first artificial planet passes much closer to the orbit of Mars than to that of the Earth. The rocket could have reached the orbit of Mars with a small increase in its launching velocity.

The last step on the path of man into the cosmos will evidently be the creation of an interplanetary satellite station on which it

would be possible for a considerable number of people to remain for prolonged periods. The creation of such a permanent cosmic station would greatly further the investigation of circumsolar space. Such a station could serve as a dispatch point for trips to the planets nearest the Earth--Mars and Venus. The bold design of man to fly to the moon and the nearest planets is near to realization. Several plans are already being worked out for such flights. Here are two of them:

The first plan proposes to accomplish flight to the moon or a nearby planet by employing an artificial earth satellite as an intermediate cosmic station. It is realized that the necessary quantities of fuel, foodstuffs, clothing for the crew, apparatus for observations, etc., can be concentrated at such a station by repeated launchings of rockets from the Earth, i.e., that a kind of "flying island" can be constructed from several artificial earth satellites. Then the crew would be disembarked there from a rocket, a new rocket would be assembled at the station, the crew would take all their necessities along with them and start out from this "flying island" to the moon, Mars, or Venus--whichever is designated in the plan.

The basic advantage of the intermediate station is the fact that it itself is in motion. As a result, a rocket bound for a planet retains its velocity in landing at such a station, and this facilitates its takeoff.

A velocity of 11.1 km/sec is required for flight to the moon.

If the earth satellite--the "Orion" island"--has a velocity of 3 km/sec. it would be necessary to impart a velocity of only 2 km/sec to a rocket for takeoff from it for the moon; for flight to Mars or Venus, this would become 3.5 km/sec. This gives a clear picture of the physical expenditure for the accomplishment of such a flight.

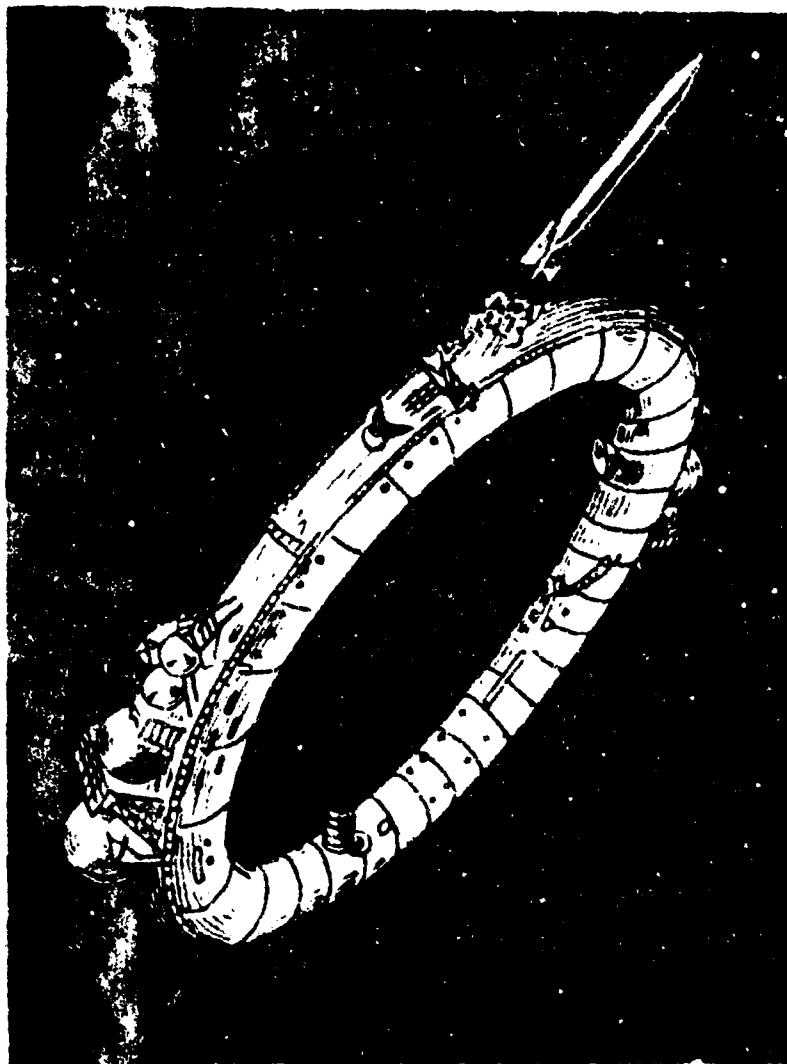


Fig. 118. Cosmic satellite station (one version).

To create artificial gravity on such a "flying island," it may be assembled in the form of a rotating circle (Fig. 118).

The conditions of flight for the crew, the conditions of landing on the moon or planet and taking off again for the return journey, and the conditions of landing on the Earth have been computed and substantiated for this version. Such a journey should be preceded by an exploratory flight of a rocket around the moon or planet without landing on it.

In the second plan it is proposed that first the moon and then the other planets be studied comprehensively without sending men to them, making extensive use instead of various types of special automatic apparatus. It is expected that this type of research on the moon and planets will require smaller expenditures of thermochemical fuel. Another important advantage of this project will be that the observance of flight conditions and the scientific investigations will be seen to not by solitary daredevils, but directly by an entire collective of scientists at special television receivers and other radio-telecommunications apparatus on the Earth.

This plan proposes that the conquest of the moon be carried out in three stages. In the first stage, an investigation of the moon would be carried out with rockets that fell onto its surface. In the flight of such a rocket, all possible data on flight conditions and the visibility of the moon from various altitudes should be transmitted by radio and television back to the Earth until the

last instant before it falls into the moon and disintegrates.

In the second stage, laboratory tanks, radio-controlled from the Earth, would be landed on the moon in rockets. Such a rocket would fly to the moon along an elliptical orbit that doubled around the lunar surface. Having attained the highest point in its orbit, the rocket would reduce speed in response to radioed commands and begin to move around the moon, gradually descending toward its surface under the influence of the lunar gravity. Correcting radio commands would provide for touchdown of the rocket in the most suitable region of the moon, the so-called Circus of Ptolemy. The laboratory tank would have transmitting television cameras controlled from the Earth, and send all observations to television receivers on the Earth as in a television broadcast of, for example, a football game from a stadium.

It is proposed that men be landed on the moon in the third stage after all preparations have been made for this: stockpiling of food, clothing, and apparatus stores, etc. The men would also transmit their observations and studies of the moon to Earth by radio and television (Fig. 119).

It is reasoned that the investigators landed on the moon will be able to stay there long enough to return to Earth in a rocket assembled on the moon from separate components landed there previously. Successive groups would be sent to relieve the first group of investigators at the lunar scientific-research station so that the inves-

tigation could proceed without interruption.

The fearless astronauts will have constant communication with the Earth and opportunities to consult with scientists in all specialties by means of tuned two-way radio and television setups. They can be given necessary advice or sent help by rocket at any time when unexpected circumstances arise. This plan suggests the use of artificial earth satellites as rocket-refueling stations.

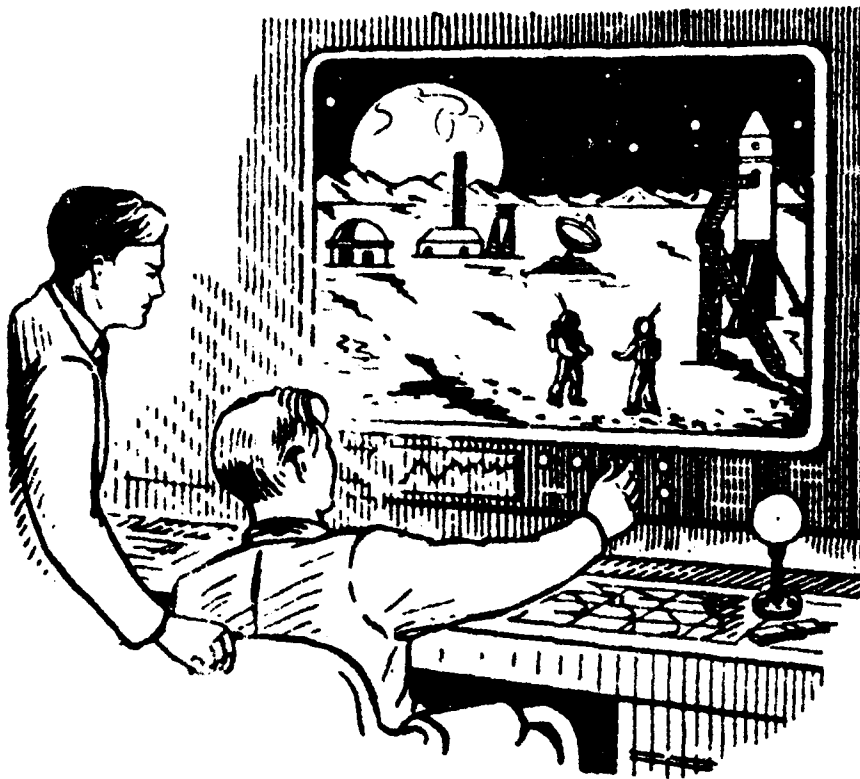


Fig. 119. Television broadcast from the moon in the near future.

A succession of flights into the distant starry Universe will follow on the heels of the flights to the moon and nearest planets.

For this, however, it will be necessary to overcome great difficulties. Even α Centauri, the nearest star to the solar system, is at a distance from us that light requires over 4 years to traverse, and the stars most distant from us are about 2 billion light-years away. How can these tremendous distances be surmounted? Even if we flew at a speed of 100 km/sec--12 times faster than the earth satellites--we could reach the nearest star only after 10,000 years. During this time many generations of astronauts would succeed one another in flight, until it befalls the last of them to gaze upon the people of an unknown world.

It is obvious that neither an ordinary contemporary rocket nor an atomic rocket, which can develop velocities of only a few tens of kilometers per second, would be capable of carrying a man into the remote starry Universe. This would require the so-called photon rocket, in which the reaction thrust will be generated by the outflow of tiny particles of light--photons emitted by matter in various reactions.

The photon rocket will be capable of developing flight speeds near the velocity of light. If a speed of about 250-290 thousand km/sec is generated with such a rocket, it will be possible to fly to α Centauri in 5 years and return in another 5 years.

The establishment of the fact of the deceleration of time at high velocities near that of light is of great interest in the prob-

lem of interstellar flight. This phenomenon follows as a consequence of one of the principles of Einstein's theory of relativity: "The value of the velocity of light in a vacuum is independent of the motion of the light source."

The deceleration of time becomes particularly pronounced at very high velocities of motion. Thus, for example, a flight to the center of the galaxy in a photon rocket will last about 20 years for the astronauts, but 200 thousand years will pass in the solar system during this period! The return from such a flight will be a "voyage into the future," since many generations of people will have succeeded one another on the Earth.

The possibility of seeing one's remote descendants seems strange now and is difficult for the human mind to conceive of. Many other problems of motion at speeds approaching that of light are still not completely solved. However, science has shown that the control of time and reduction of colossal distances are in principle possible.

Flight to other galaxies is as yet practically impossible. This will come about not today, not tomorrow, but in the day-after-tomorrow of science and technology.

The launching of the first Soviet artificial earth satellite, which marked the beginning of the era of the conquest of the cosmos, stands as one of a series of such turning points in the historical development of human society as the discovery of fire, the invention of steam engines, the discovery of electrical current and its effect

on magnets--the origin of electrical engineering--, the flight of the first airplane, and the liberation of the energy of the atomic nucleus.

The first artificial satellite of the Earth was created by the genius of the Soviet people. This fills us with a feeling of justified pride in our science and in the fact that the Soviet Union has forged ahead to first place in the world in many branches of knowledge.

And as cosmic space is mastered in the time to come, socialist science and technology and the Soviet people will make a meritorious contribution to the progress and good fortune of mankind.

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2167

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